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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

02102860.0

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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R C van Dijk

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Sheet 2 of the certificate
Page 2 de l'attestation

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UNITED STATES OF AMERICA

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High accuracy laser fine autofocus system

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D E S C R I P T I O N

High Accuracy Laser Fine Autofocus System

1. BACKGROUND OF THE INVENTION

1.1. FIELD OF THE INVENTION

The present invention relates to the field of optical probe surface inspection by interferometry, and in particular to a method and apparatus for fine-controlling the position of a predetermined probe location relative to a fixed reference point of a probe processing apparatus fixedly coupled to an auxiliary optical laser apparatus in which method the position is controlled with optical means.

1.2. DESCRIPTION AND DISADVANTAGES OF PRIOR ART

Such prior art system is disclosed in US patent 5,469,259 to IBM Corporation, Armonk, USA. In said system a surface profile interferometer is used as a device for determining the roughness of a surface or the height of a step change in the thickness of a part being measured. Such a step change may be caused, for example, by the application of a metal film to a substrate in the manufacture of a printed circuit board or an integrated microcircuit. In general terms, an interferometer is an optical instrument in which two beams of light derived from the same monochromatic source are directed along optical paths of different length, in which the difference in length determines the nature of an interference pattern produced when the light beams are allowed to interfere. Since the beams of light are derived from the same monochromatic source, they are identical in wavelength. At equal path distances from the source, they are also in phase with one another. Phase differences between the beams therefore result only from differences in path length.

The phenomenon of light wave interference results from the mutual effect of two or more waves passing through the same region at the same time, producing reinforcement at some points and neutralization at other points, according to the principle of superposition.

With a photoelectric shearing interferometer, the height of a step change in a test surface may be measured using polarized light passed through a slit, through a Wollaston prism, and through a microscope objective lens, to form two images of the slit, with one image on each side of the step change. The beams reflected by the test surface pass through the lens and the prism, with an image being formed by two orthogonally polarized beams. The phase difference between these beams, which is determined by the height of the step, may be measured by the linear movement of a weak lens in a lateral direction (transverse to the beam) until the phase difference is exactly cancelled, as determined by the use of an electro-optic modulator, an analyzer, a photomultiplier, and a phase-sensitive detector, which are used together to detect the phase equality of the two interfering beams. The accuracy of the system depends on the precision to which the linear movement of the weak lens can be measured.

In the above-mentioned US patent a separate autofocus system is required for maintaining the focus of the main imaging path of the interferometer. This is done by a separate arrangement according to confocal technique, i.e. to control the intensity of a target spot and maintaining the intensity at the maximum level. A disadvantage is that too many optical elements are used which makes the autofocus system difficult to adjust and renders it error-prone.

1.3. OBJECTIVES OF THE INVENTION

It is thus an objective of the present invention to provide a method and respective system for positioning a predetermined probe location in an automated way and avoiding the disadvantages of confocal autofocus systems.

2. SUMMARY AND ADVANTAGES OF THE INVENTION

This objective of the invention is achieved by the features stated in enclosed independent claims. Further advantageous arrangements and embodiments of the invention are set forth in the respective subclaims. Reference should now be made to the appended claims.

According to the broadest aspect of this present invention a method is disclosed for fine-controlling the position of a predetermined probe location relative to a fixed reference point of a probe processing apparatus, which is understood to be the actual device which takes profit from the inventive fine-control, e.g., a laser microscope, a common optical microscope, a laser scan apparatus, a read/write laser in a consumer electronic device, like a CD-player, a DVD player, an optical storage device, etc., whereby said probe processing apparatus is fixedly coupled to an auxiliary optical laser apparatus, whereby the position is controlled with an optical device.
Said method is characterized by the steps of:
a) presetting said probe location position within a predetermined converging range of 1/4 of the wave length of the applied fine-controlling positioning laser beam,
b) splitting said positioning laser beam having a linear polarity into a probe beam (S2) and a reference beam (S1), whereby a respective optical beam splitting means represents said fixed reference point,
c) polarizing said probe beam and said reference beam in different directions, preferred perpendicular to each other,

d) recombining a beam reflected from said probe location with said reference beam,

e) detecting a phase difference between said reflected beam and said reference beam, and

f) controlling a table supporting said probe, such that the detected phase difference is minimum.

The table may be advantageously piezo-driven, as it is known in prior art. The main advantage of this basic inventive method is that the inventive system is built without lenses, and that a simple setup could be used, as it will be later described with reference to fig. 1.

Further, when the above mentioned method steps b) to f) are repeated continuously for a plurality of probe locations while scanning a continuous portion of a probe surface, the inventive principle can also be used for scanning large scale surfaces, as they occur in diverse industries, as e.g. chip surfaces.

Further, said auxiliary optical laser apparatus may be advantageously used to perform a fine-controlled auto-focusing of a process laser beam. Then, the respective process laser beam is associated with said probe processing apparatus. Multiple examples exist, in which the invention may be applied:
A Laser (Scan) microscope, a laser system used or abrasive purposes, for reading data from a storage media (CD, DVD, Magneto-optical disk, etc.), and finally any mechanical tool having a kind of small tip which interacts in a particular dedicated way with a respective surface of a probe, for example an Atomic Force Microscope, a mechanically operating profiler touching and scanning a probe surface, etc..

In a particular example of use the inventive method can be used to perform a fine-focusing of a microscope apparatus acting as said probe processing apparatus. By that the accuracy of a prior art microscope focusing method can be improved by a factor of

100, approximately, as a focus can be set with an accuracy of about 1 nanometer, depending on the electronic control device of the applied auto focus system.

Further, an apparatus having means for performing the above-mentioned steps is disclosed, of which a preferred example is described in more detail with reference to fig. 1.
Preferably, the means for performing steps b) and c) of above method is a polarizing beam splitter. By that the apparatus is easier to adjust, and less optical elements are used.

Further, advantageously, said means for detecting said phase difference comprises:
a) either a quarter-wave-plate or a Babinet-Soleil-Compensator modifying the polarity of said recombined beam,
b) a polarizing beam splitter (ST4) post-connected thereto, and
c) a pair of photo detection means, e.g., photo diodes sensing the respective intensity of the split beams for control purposes.

3. BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and is not limited by the shape of the figures of the drawings in which:

Fig. 1 is a block diagram representing a preferred embodiment of the apparatus used in the inventive method, in which the inventive auxiliary optical laser apparatus is shown, and an actual probe processing apparatus is suppressed for sake of clarity;

Fig. 2 is a block diagram representation illustrating the basic steps of the inventive method;

Fig. 3 is a schematic physical view representation primarily illustrating the relation ship in size of a probe surface and the presetting range in an inventional apparatus, and

Fig. 4 is a schematic representation primarily illustrating the selection of the polarization direction of the incoming laser beam relative to that of the split beams.

4. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With general reference to the figures and with special reference now to fig. 1 and 2, after a rough preset - step 205 of the auxiliary laser system, a collimated laser input-beam, for example a Helium-Neon laser, which is linear polarised -or any other linear polarized laser system- is denoted with reference sign 10. The input-laser beam impinges onto a polarising beam splitter abbreviated as ST1 in the drawing and having reference sign 12. The incoming beam splits up - step 210 - into a reference beam S1 -reference sign 14, having a polarity normal to the paper plane of fig. 1, and into a transmissive beam S2 - reference sign 16, having a polarity-direction along the X-axis within the paper plane in fig. 1 - step 215.

The reference beam S1 is denoted with reference sign 14, whereas the beam passing through beam splitter 12 is further referred to herein as "probe beam", having reference sign 16. The probe beam is further transmitted through a second beam splitter 18, denoted as ST2, and is reflected from a predetermined probe location of probe 20, which is in turn supported by a piezo-driven support-table 22. The reflected beam 17 is reflected at beam splitter 18 to a redirecting mirror 24 and enters into a further beam splitter, denoted as ST3, having reference sign 26. In said beam splitter 26 the reflected beam 17 is recombined with the reference beam 14, denoted as S1, step 220.

Then the recombined beam enters an arrangement for detecting - step 230 - a phase difference between said reflected beam and said reference beam, which is denoted by reference sign 30 and encircled by a rectangle in broken lines.

In more detail the recombined beam first enters a commercially available quarter-wave-plate 32, which modifies the polarisation of the combined laser beam for evaluation purposes. After transmission through said quarter-wave-plate 32, the combined beam enters into a further beam splitter 34 having again polarising properties (like beam splitter ST1, 12). Beam splitter 34 splits up the combined beam into two different beams which are perpendicularly polarized to each other, the intensity of which is sensed in photo detectors 36 and 38, respectively.

The intensity values measured by photo detectors 36 and 38 which may advantageously be implemented as photo diodes, are further processed in a control-algorithm 40 which performs the inventionally provided fine-control 240 of the Z-position (top/down of the piezo-driven support-table 22) according to a given control aim, for example the difference signal value shall be minimum.

When the probe location, which optically reflects the probe beam 16, is moved in top- or down-direction (Z-direction) by the control 40, the phase difference between the probe-reflected beam 17 and the reference beam 14 is modified, respectively. Three scenarios, of which all can be advantageously evaluated according the present invention, are given next in order to illustrate the ranges, in which the phase differences and thus the polarisation of the combined beam may vary. A respective difference-signal may for example be defined as: amplitude of photo-diode signal 36 minus amplitude of photo-diode signal 38:

(A) If the phase difference between reference beam and reflected beam is an integer multiple of the half of the

laser-wave-length, then, the recombined laser beam entering the quarter-wave-plate 32 is again linear polarised. In this case, the quarter-wave-plate 32 moves the polarisation of the laser beam from linear to circular. The circularly polarised beam is split by beam splitter 34 in equal intensities and thus, the intensities sensed by the photo-diodes 36 and 38 are equal. Thus, after a respective amplification of the difference-signal the control algorithm 40 is fed by a control signal with a minimum value, for example normalised to zero. In this case no control will be necessary, as the probe location, reflecting beam 17 is in the desired exact Z-position.

(B) If the phase difference is maximum, i.e. + 90 ° or - 90 °, then the combined laser beam entering into quarter-wave-plate 32 as a respective, circular (right or left) polarity, which is modified by polarising beam splitter 34 into a linear polarity, which results in a maximum intensity at either of the photo-diodes 36 or 38 with a respective minimum-value at the respective other photo-diode. Then the difference-signal which is used by the control-algorithm 40 is maximum, whereby the sign of the difference-signal is used in order to determine the moving-direction, in which the piezo-table will be moved in order to achieve the control-aim, i.e. a phase difference of zero.

(C) If the polarity of the combined beam is in general elliptic orientated, the polarity will not be changed after passing the quarter-wave-plate 32. Only the orientation of the elliptic polarity will be changed. In this general case the photo-diodes 36 and 38 send in most cases different intensities, resulting in a difference control signal, which is used in control algorithm 40 to move the support-table 22 in the correct direction, indicated by the sign of the difference-signal.

It should be noted that prior to perform a computerised control as described above the signal which is subjected to the control-algorithm must be calibrated in order to achieve a coincidence between a minimum difference-signal and the desired probe location.

When for example, the desired probe location is the centre of a focal volume of a CD-laser beam, the calibration procedure comprises to set the optical arrangement given in fig. 1 such that the difference-signal is minimum in that desired position. This can for example be done by setting the polarisation-angle with reference to the beam of the above-mentioned quarter-wave-plate. Further, the piezo-driven probe-support-table 22 may be wobbled accompanied by a manual oscilloscope-control of the resulting error-signal, in order to obtain a good calibration.

It should be added, that the optical elements mentioned in here as polarising beam splitters 12 and 34, respectively, may also be modified by replacing them by a non-polarising beam splitter followed by a respective polarising element, such as a foil or a crystal. Further, instead of said polarising beam splitters it is also possible to apply polarising prism devices, like Wollaston-Prism or Glan Thomson-device. Further, instead of applying a quarter-wave-plate 34 a Babinet-Soleil-Compensator can be applied, as well.

With further reference to **fig. 3** a further preferred application of the basic principle of the present invention is described in more detail:

The line 42 is intended to illustrate a cross section of a probe surface with the depicted X-Z-plane, in which a laser scan apparatus is continuously moved while its processing laser beam focus is maintained at the desired location directly at the

probe surface with the aid of the inventional principle. Thus, in this example the laser scan apparatus is the so-called probe processing apparatus according to the wording in the claims. The fine-controlled positioning laser beam, which is denoted with reference sign 16 in fig. 1, however, is used within an auxiliary optical laser apparatus fixedly coupled to the before-mentioned probe processing apparatus.

In order to achieve that both, the processing beam -not shown- and the positioning beam 16 may be directed very close to each other focussed at a small spot at the probe surface 42. It is obvious for a person skilled in the art, that the auxiliary optical laser apparatus and the actual probe processing apparatus must be fixedly and stiff coupled together in order to achieve that any movement resulting from the control described above with reference to fig. 1 results in a respective movement of the probe at basically the same location relative to the actual processing laser beam.

In fig. 3 the converging range 40 is illustrated in relation to the roughness of the probe surface in order to illustrate the relationship between them two. The converging range 40 must be smaller than a quarter of the wavelength of the positioning laser beam. In case the wavelength is 800 nanometres, the range 40 is thus 200 nanometres. Thus, after the before-mentioned rough pre-setting 205 of the probe laser beam has been performed, the probe surface which is desired to be in the focus of the processing beam lies within the converging range. Thus, as a person skilled in the art will appreciate, a continuous movement in X-direction or Y-direction may be performed between the probe surface and the above-mentioned two fixedly coupled apparatuses in order to perform a laser scan procedure according to prior art. The advantage results that a very fine-controlled autofocus system is provided by the present invention. The fine control is achieved in the range of a about 1 nanometer.

A further preferred application of the inventive principle comprises to perform a fine control in the focussing procedure of a microscope. Prior art high quality microscopes have a focussing accuracy, which is about some 100 nanometers only. By virtue of the invention the auxiliary optical laser apparatus described above with reference to fig. 1 may be fixedly coupled to the microscope and the optical focus of the objective may be fine controlled according to the above description. In this example the calibration procedure must be adapted in order to reflect the very best focus setting at a predetermined probe location. This calibration procedure, however, must be performed only once supposed the probe surface has no vertical steps larger than the converging range depicted in fig. 3.

With additional reference to **fig. 4** the polarization direction of the incoming laser beam 10 relative to that of the split beams X and Y, respectively, is illustrated. The angle a between the polarisation direction of the input-beam and the polarisation direction of the split beams 14, 16, respectively, must be different from zero and 90° and is preferred 45° (decimal degree). When it is 45°, the intensity of the split beams 14, 16 is equal. When using other angles than 45°, the intensity of the split beams 14, 16 varies as a function of the angle a. Polarisation directions are also indicated in the drawing of fig. 1 by respective arrows and usual symbols.

Further, according to a further advantageous aspect of the present invention the above angle a can also be set or controlled differently, in order to render the control easy by including the extent of the reflectivity of the focused probe location: when the angle a (s. Fig. 4) between the polarization direction of the incoming laser beam 10 and the polarisation direction of said reference beam 14 or the probe beam 16, respectively, is selected such that the intensities of reflected probe beam and reference beam - when entering the phase detection means 30 -or the quarter-wave plate 32 in particular,

are equal, then the advantage is reached that the subsequent control for photo-detector signal difference being a minimum value - is easy to implement. This reflects the varying reflectivity of different probe locations. Thus for example, an angle a of 30° may be also selected as best suited for a given reflectivity value of e.g. 40%.

C L A I M S

1. A method for fine-controlling the position of a predetermined probe (20) location (21) relative to a fixed reference point (12) of a probe processing apparatus fixedly coupled to an auxiliary optical laser apparatus, in which method the position is controlled with optical means, characterized by the steps of:
   a) presetting (205) said probe location position (21) within a predetermined converging range (40) of 1/4 of the wave length of the applied fine-controlling positioning laser beam (10,14,16,17),
   b) splitting (210) said positioning laser beam (10) having a linear polarity into a probe beam (S2) and a reference beam (S1), whereby a respective optical beam splitting means (10) represents said fixed reference point,
   c) polarizing (215) said probe beam (16) and said reference beam (14) in different directions to each other,
   d) recombining (220) a beam (17) reflected from said probe location (21) with said reference beam (14),
   e) detecting (230) a phase difference between said reflected beam (17) and said reference beam (14), and
   f) fine-controlling (240) a table supporting said probe, such that the detected phase difference is minimum.

2. The method according to claim 1, in which the angle a between the polarization of the incoming laser beam (10) and the polarisation direction of said reference beam (14) or the probe beam (16), respectively, is 45°.

3. The method according to claim 1, in which the angle a between the polarization of the incoming laser beam (10) and the polarisation direction of said reference beam (14) or the probe beam (16), respectively, is selected such that the intensities of reflected probe beam and reference beam

- when entering the phase detection means (30) are equal.

4. The method according to claim 1, in which the method steps b) to f) are repeated continuously for a plurality of probe locations (21) while scanning a continuous portion of a probe surface.

5. The method according to claim 1, in which said auxiliary optical laser apparatus contributes to perform a fine-controlled auto-focusing of a laser beam associated with said probe processing apparatus.

6. The method according to claim 1, in which said auxiliary optical laser apparatus contributes to perform a fine-focusing of a microscope apparatus acting as said probe processing apparatus.

7. An apparatus having means for performing the steps of the method according to claim 1.

8. The apparatus according to the preceding claim in which said means for performing steps b) and c) of claim 1 is a polarizing beam splitter (12).

9. The apparatus according to claim 5 or 6, in which said means (30) for detecting said phase difference comprises:
a) either a quarter-wave-plate (32) or a Babinet-Soleil-Compensator modifying the polarity of said recombined beam,
b) a polarizing beam splitter (34) (ST4) post-connected thereto, and
c) a pair of photo detection means (36, 38), sensing the respective intensity of the split beams for control purposes.

A B S T R A C T

High Accuracy Laser Fine Autofocus System

The present invention relates to the field of optical probe surface inspection by interferometry, and in particular to a method and a respective apparatus for fine-controlling the position of a predetermined probe location (21) relative to a fixed reference point (12) of a probe processing apparatus fixedly coupled to an auxiliary optical laser apparatus, in which method the position is controlled with optical means. In order to simplify the apparatus it is proposed to provide a simply structured fine-control positioning system also based on the principle of interferometry. Basically, a lens-less optical arrangement is provided which uses a collimated input laser beam (10) and performs the following steps:

a) presetting said probe location position within a predetermined converging range of 1/4 of the wave length of the applied fine-controlling positioning laser beam (10),

b) splitting said positioning laser beam having a linear polarity into a probe beam (S2, (16) and a reference beam (S1, 14), whereby a respective optical beam splitting means (12) represents said fixed reference point,

c) polarizing said probe beam (16) and said reference beam (14) in different directions to each other,

d) recombining a beam (17) reflected from said probe location with said reference beam (14),

e) detecting a phase difference between said reflected beam and said reference beam, and

f) controlling a table supporting said probe, such that the detected phase difference is minimum. (Fig. 1)

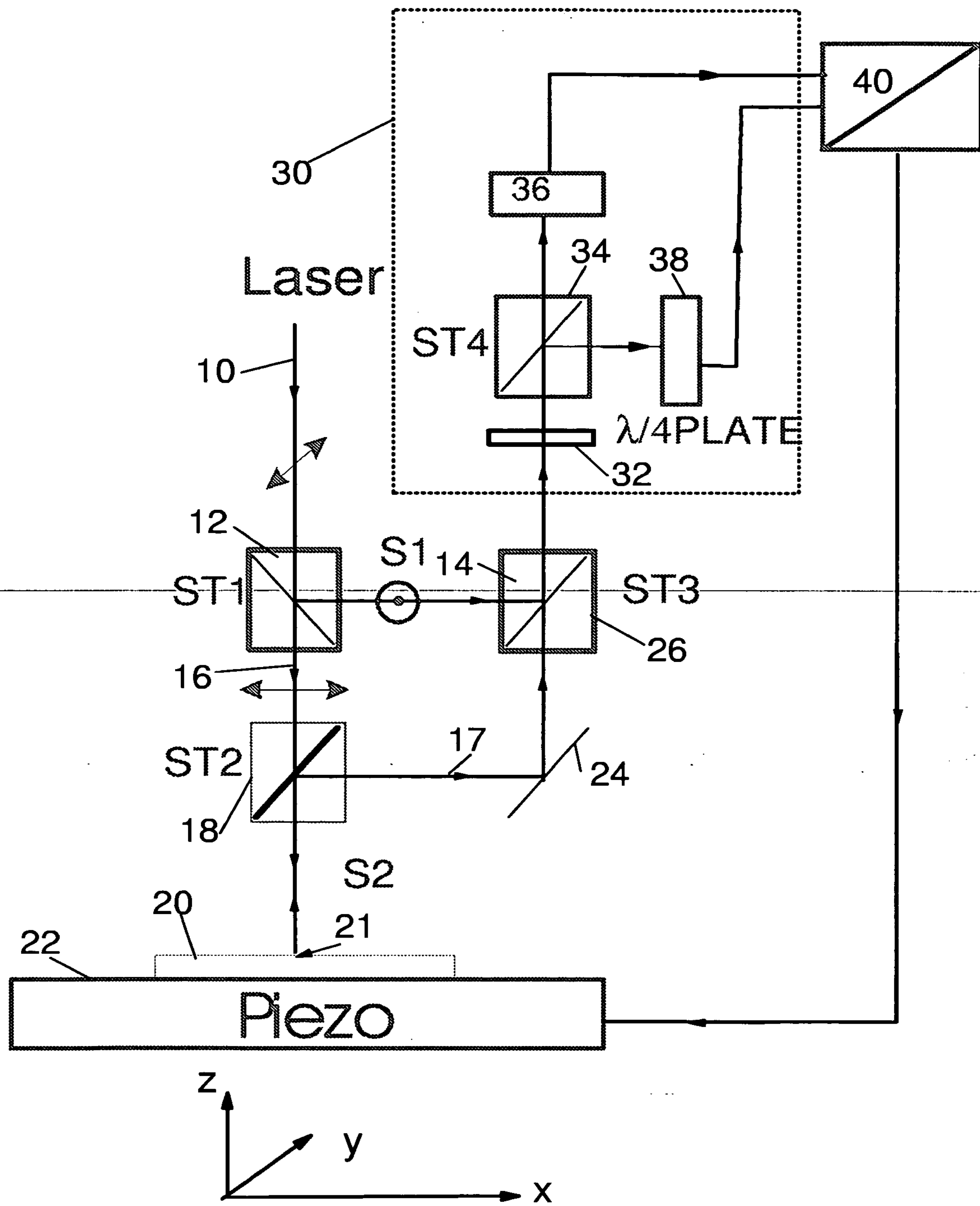

FIG. 1

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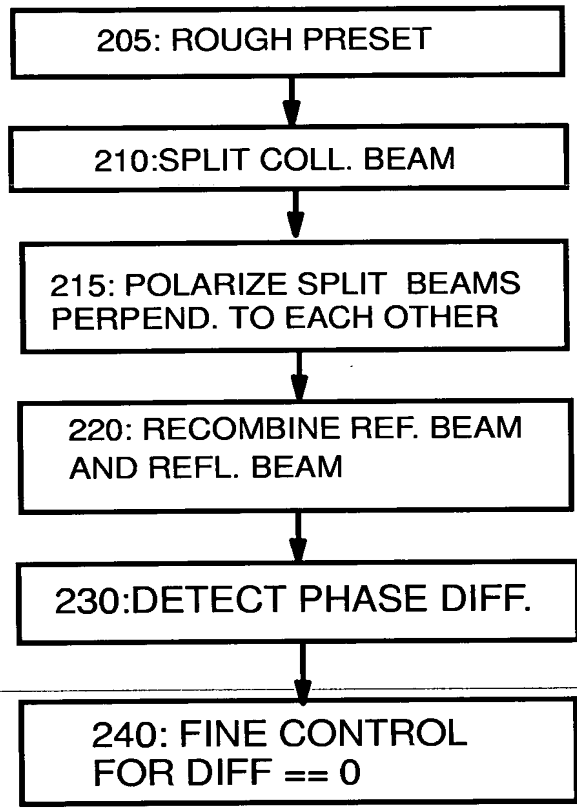
205: ROUGH PRESET
210:SPLIT COLL. BEAM
215: POLARIZE SPLIT BEAMS PERPEND. TO EACH OTHER
220: RECOMBINE REF. BEAM AND REFL. BEAM
230:DETECT PHASE DIFF.
240: FINE CONTROL FOR DIFF == 0

FIG. 2

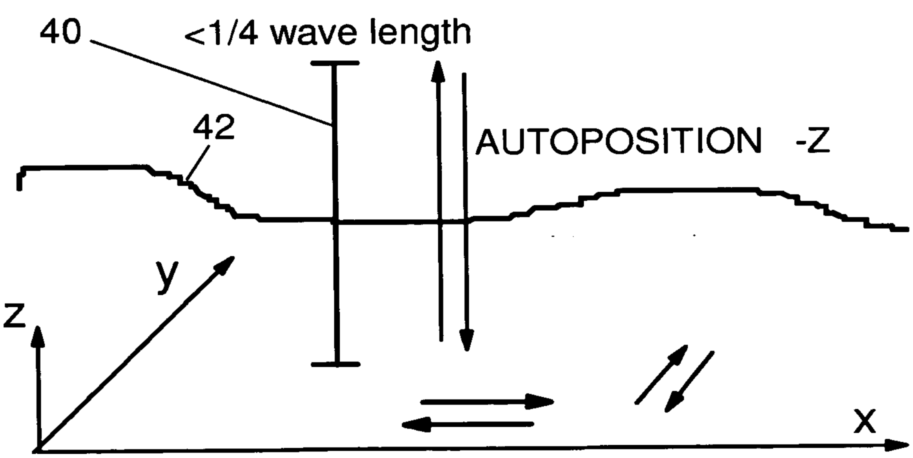
40
<1/4 wave length
42
AUTOPOSITION -Z
y
z
x

FIG. 3

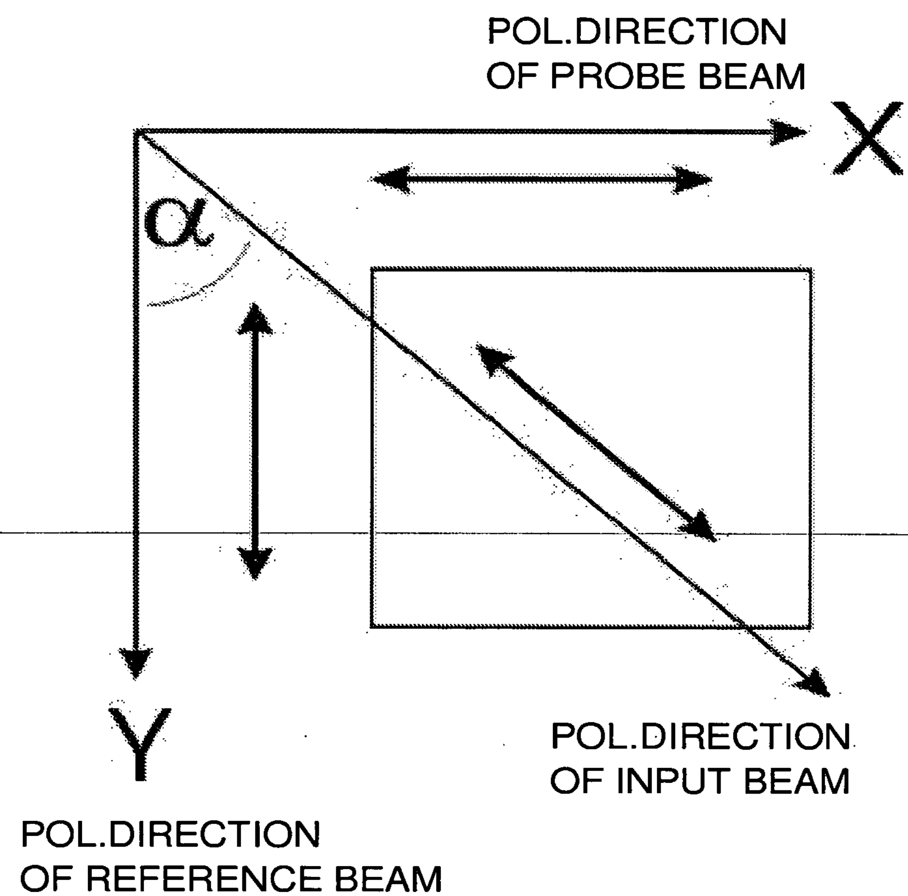

FIG. 4

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